RELIABILITY-BASED ANALYSIS AND DESIGN OPTIMIZATION OF MEMS

M. Allen[a], **M. Raulli**[a] and **K. Maute**[a]

[a]Center for Aerospace Structures
The University of Colorado
Boulder, Colorado 80309-0429
matthew.allen@colorado.edu

A computational methodology is presented for the high-fidelity electrostatic-mechanical reliability analysis and the Reliability-Based Design Optimization (RBDO) of Micro-Electro-Mechanical Systems (MEMS). While the potential of MEMS is widely recognized, the use of MEMS is hampered by reliability problems, that is, MEMS devices often fail before reaching their required life-time. Basic failure mechanisms and uncertainties in structural parameters and operating conditions need to be accounted for, in order to design reliable MEMS. This problem, however, is further complicated by the fact that MEMS sensing and actuation mechanisms typically exploit the interaction of multiple physical fields, such as electrostatic-mechanical coupling.

The presence of the aforementioned uncertainties render conventional deterministic analysis and optimization techniques unable to accurately predict the performance of MEMS devices. Subsequently, deterministic optimization methods are unable to create reliable MEMS designs. Therefore, we employ the First Order Reliability Method (FORM), as a means of predicting the stochastic behavior of MEMS mechanisms. FORM is a first order approximation of the limit state function at the Most Probable Point (MPP) of failure in the standard normal space of the uncertainty parameters. We study the linearity of the limit state functions using Monte Carlo simulation to verify the utility of the first order approximation. Once verified, the FORM analysis is integrated into a RBDO framework. A fully-coupled, electrostatic-mechanical finite element model is employed to analyze a given representation of the MEMS device. Our approach is based on a three-field formulation, where the third field represents the mesh motion of the electrostatic domain. The analytical sensitivities of the governing equations are developed for the efficient and accurate calculation of the gradients, as both the MPP optimization problem and the design optimization utilize gradient-based methods.

To test the developed methods we use a silicon carbonitride (SiCN) MEMS actuator for which there is a collection of experimental data available. The actuator consists of an upper and lower plate with an air gap between, over which a voltage is applied to actuate the device. The greatest sources of uncertainty for the device have been the inability to accurately control the following during the manufacturing process: the air gap between the plates, the curvature of the upper SiCN plate, and the material properties. Both experiment and simulation have shown that these uncertainties in manufacturing lead to an inability to predict the performance of the device, even under controlled operating conditions. These uncertainties will be modeled in the proposed method to understand their effect on the stochastic system and to optimize the device for both reliability and performance. Within the RBDO process, the probability of different modes of failure will be constrained to tolerable levels, and the probability of achieving a specified displacement for each voltage, or the accuracy of the actuator, will be maximized.